

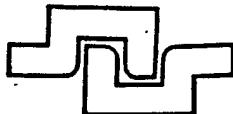
# REPORT DOCUMENTATION PAGE

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4. TITLE AND SUBTITLE General Report: Sonochemistry and Sonoluminescence Conference			5. FUNDING NUMBERS N00014-97-1-0149	
6. AUTHOR(S) Lawrence A. Crum				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Applied Physics Laboratory Universityy of Washington 1013 NE 40th Street Seattle, WA 98105-6698			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Office of Naval Research, ONR 331 800 N. Quincy Street Arlington, VA 22217-5660			10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES <p>The full Proceedings of the NATO ASI conference will be published by Kluwer in 1998.</p>				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release. Distribution unlimited.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) <p>This report summarizes activity at the NATO Advanced Study Institute conference on sonoluminescence and sonochemistry, held at Leavenworth, WA, 18-29 August 1997. Over 70 attendees from 19 countries participated in the conference. Details on the participants are provided in the report. The conference was successful in bringing together international experts in both sonochemistry and sonoluminescence, which may forge future collaboration and a more general investigation of the field.</p>				
14. SUBJECT TERMS sonoluminescence, sonochemistry, acoustic cavitation, bubble implosion, light emission			15. NUMBER OF PAGES 13	
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# NATO International Scientific Exchange Programmes

## ADVANCED STUDY INSTITUTE

Scientific Affairs Division - NATO - B-1110 Brussels Belgium - Telephone: 02/728.42.31 - Telex: 23-867 (NATOHQ)

### GENERAL REPORT

**Note**

*This report should be sent within 30 days of the meeting. The financial report (pink form) may be sent later after consolidation of the accounts; however it must be with NATO by not later than 120 days from the end of the meeting. It should be recalled that only after acceptance by NATO of the financial report as well as the present report can any final supplementary award be authorized.*

**1. Advanced Study Institute**

**Title:** Sonochemistry and Sonoluminescence

**Location:** Sleeping Lady Conference Center  
*(site and country)* Leavenworth, Washington, USA

**Dates:** 18-29 August 1997  
**Number of working days:** 10

**2. Director:**

*(name, position, official address, telephone no., telex no.)*

Lawrence A. Crum, professor, 1013 NE 40th Street, Seattle, Washington, 98105-6698, USA,  
 T (206)685-8622, F (206)543-6785

**3. Principal Members of the Organizing Committee**

*(name, position, official address)*

Timothy J. Mason, professor, School of Chemistry, Priory Street, Coventry University, Coventry CV1 5FB,  
 United Kingdom

Jacques L. Reisse, professor, Service de Chimie Organique, Université Libre de Bruxelles,  
 Avenue F.D. Roosevelt 50, 1050 Bruxelles, Belgium

Kenneth S. Suslick, professor, School of Chemical Sciences, University of Illinois, 263 N1,  
 Box 13 - 505 S. Mathews, Urbana, Illinois, 61801, USA

**4. Scientific Codes and percentages of discipline content (see NATO classification of scientific subjects)**

Code	%	Code	%	Code	%
221	45	316	35	200	20

##### **5. General Comments**

The topic that we chose, Sonoluminescence and Sonochemistry, is one that recently has received considerable publicity, and thus resulted in an ASI that probably was somewhat atypical. In particular, we received many applications from established researchers in the field, some who had extremely strong reputations in scientific research. Consequently, simply out of courtesy to our distinguished participants, we felt it necessary for them to also provide some lectures on their areas of specialty. When we organized our lecturers, we selected the top ones active in the field; however, in the interim between the selection of lecturers and the time for the ASI itself, there were a considerable number of new researchers who had entered the field. On the other hand, we also had many applications from interested, but inexperienced, researchers from emerging countries, such as Turkey, Portugal, Romania, etc. who we felt would greatly benefit from the Institute. Thus, the range of background knowledge of our participants was extremely large. This wide range made construction of a lecture program rather difficult. We eventually addressed this problem by presenting some introductory tutorial information, but also permitted the (distinguished and knowledgeable) participants to play a more active role in the program.

We discovered that there were two groupings of applications. The first were those that we essentially recruited by our own mailings of a brochure that we developed. This group was the largest group of applicants. A second group were those who saw the NATO listings and found the topic of interest. This second group was typically much less familiar with the topic than the first group, and thus presented the background difficulty described in the preceding paragraph. It is possible that we could have filled our allotment of participants from the first group, but rather unlikely from the second group. It appears as if there are some individuals who apply to many of the NATO listed ASIs, even if they have little knowledge about the subject.

Because we did some extensive recruiting of participants for the ASI ourselves, we had some feedback as to what aspects of the ASI attracted them and what aspects prevented them from coming. Many individuals indicated to us that they would have applied if the time period were shortened to one week; on the other hand, many were attracted to the conference because it was thought that the length of the ASI was sufficient to really delve into a topic with some considerable depth. In general, it seems as if 11 days was about 3 or 4 days too long. A shorter time period is recommended. Still, our program was so packed with lectures and discussions that there was little inactive time; indeed, everyone was so worn out by the end of the conference that a discussion period on the last day had to be canceled.

In our conference, we had over 70 participants (counting lecturers) from 19 different countries. Furthermore, we selected a venue that was quite isolated, thus requiring most of the participants, who did not rent cars, to remain on the grounds of the conference center for the entire period. This isolation had two effects: First, technical discussions were ongoing from early morning until late at night; thus, we were able to deal with various topical issues in great depth. The depth of our discussions led to both positive and negative aspects. It was quite rewarding to discuss an issue for hours until everyone had their say on a topic; however, differences in opinions occasionally led to personality disagreements and we actually had a few shouting matches. Second, because we lived together and interacted together for nearly two weeks, strong personal interrelationships developed. Many of the participants formed friendships and collaborations that will last for many years. Indeed, we have heard of several planned trips that participants have scheduled to follow up on both personal and technical issues.

Finally, for a variety of reasons, this ASI was so successful that we have had comments from probably half the participants who said that this conference was the BEST that they ever attended. We are thus indebted to NATO for giving us this wonderful opportunity.

**6. National distribution of Lecturers (L) and ASI Students (S)**

	L	S		L	S		L	S		L	S
Belgium	2	3	Iceland	0	0	Spain	1	1	Other Countries <i>(specify)</i>		
Canada	0	4	Italy	0	4	Turkey	0	3			
Denmark	0	0	Luxembourg	0	0	UK	2	5			
France	0	2	Netherlands	0	1	USA	7	15	(see attached)		
Germany	1	6	Norway	0	1						
Greece	0	0	Portugal	0	2						
									TOTALS		
										13	60

**7. Book to be published as a product of the ASI**

**Title of Book :**

Sonochemistry and Sonoluminescence

**Editor(s) : (a)**

Lawrence A. Crum

(b)

Timothy J. Mason

(c)

Jacques L. Reisse

(d)

Kenneth S. Suslick

**Publisher :**

Kluwer

**Expected Date of Publication :**

Summer 1998

**Editor's Comments**

**Date :**  
29 September 1997

**Attachments**

1. Annex - List of Director(s), Lecturers and ASI Students
2. Scientific summary : camera ready

**Signature**

OTHER COUNTRIES:

	L	S
Russia	0	4
Estonia	0	1
Slovakia	0	1
Japan	0	2
Australia	0	2
Israel	0	1
Finland	0	2

**GENERAL REPORT  
ASI**

**ANNEX**

**LIST OF DIRECTOR(S), LECTURERS AND ASI STUDENTS**

*Notes : - It is suggested that before completing the present form you make photocopies of it in order to have enough copies for your requirements.*

- Please group by country in alphabetical order.
- The Director's list of participants can be accepted as a substitute for this form provided all the information required below is given.

NAME	FULL OFFICIAL ADDRESS /Institution, Street, Town, Country/
(a) Director(s)	Lawrence A. Crum Applied Physics Laboratory, University of Washington, 1013 NE 40th St., Seattle, Washington 98105, USA
(b) Lecturers	Thierry Lepoint Jacques Reisse Institut Meurice-Bat 10, 1, Avenue Emile Gryson, 1070 Brussels, Belgium Service de Chimie Organique, Avenue F.D. Roosevelt 50, 1050 Brussels, Belgium
	Werner Lauterbom Universitaet Gottingen, Buergerstr. 42-44, D-37073 Gottingen, Germany
	Juan A. Gallego-Juarez Consejo Superior de Investigaciones Cientificas, Instituto de Acustica, Calle Serrano, 144, 28006 Madrid, Spain
	Timothy J. Mason Gareth J. Price School of Chemistry, Coventry University, Priory Street, Coventry CV1 5FB, United Kingdom
	School of Chemistry, University of Bath, Claverton Down, Bath BA2 7AY, United Kingdom

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NAME	FULL OFFICIAL ADDRESS /Institution, Street, Town, Country
(a) Director(s)	Mason Laboratory, Dept. of Mechanical Engineering, Yale University, Box 2159 Yale Station, New Haven, Connecticut, 06520, USA Bell Labs / Lucent Technologies, 700 Mountain Ave., Murray Hill, New Jersey, 07974, USA Applied Physics Laboratory, University of Washington, 1013 NE 40th St., Seattle, Washington 98105, USA Institute for Nonlinear Science, University of California at San Diego, La Jolla, California 92093, USA Johns Hopkins University, Department of Mechanical Engineering, 117 Laurobe Hall, Baltimore, Maryland, 21218, USA Boston University, Department of Aerospace and Mechanical Engineering, 110 Cummingston St., Boston, Massachusetts, 02215, USA School of Chemical Sciences, University of Illinois at Urbana-Champaign, 263 N1, Box 13- 505 S. Matthews, Urbana, Illinois, 61801, USA
(b) Lecturers	Robert Apfel Bradley Barber Lawrence A. Crum Michael Longuet-Higgins Andrea Prosperetti Ronald A. Roy  Kenneth S. Suslick

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NAME	FULL OFFICIAL ADDRESS /institution, Street, Town, Country
(c) ASI Students	
Muthupandian Ashokkumar Franz Grieser	AMPC, School of Chemistry, University of Melbourne, Parkville, VIC 3052, Australia Advanced Mineral Products Centre, School of Chemistry, University of Melbourne, Parkville 3052, Australia
Kristin Bartik Francoise Lepoint-Mullie Nicolas Segebarth	Service de Chimie Organique, Avenue F.D. Roosevelt 50, 1050 Brussels, Belgium Institut Meunice-Bat 10, 1, Avenue Emile Gryson, 1070 Brussels, Belgium Service de Chimie Organique, Avenue F.D. Roosevelt 50, 1050 Brussels, Belgium
David Cheeke Manas Dan Jean-Luc Dion John Russell Ants Tuulmets	Concordia University, Physics Department, 1455, de Maisonneuve Blvd. West, Montreal Quebec H3G 1M8, Canada Concordia University, Physics Department, 1455, de Maisonneuve Blvd. West, Montreal Quebec H3G 1M8, Canada Universite du Quebec a Trois-Rivieres, 3351, Bd des Forges, Trois-Rivieres cp 500, Quebec G9A 5H7, Canada British Columbia Research Institute, University of British Columbia, Vancouver, British Columbia, Canada University of Tartu, Faculty of Physics and Chemistry, Institute of Organic Chemistry, Jakobi 2, EE2400 Tartu, Estonia
Marti Salomaa Anne Sarkilahti	Materials Physics Laboratory, Department of Engineering Physics and Math., Helsinki University of Technology, PO Box 2200, FIN-02150 HUT, Espoo, Finland Materials Physics Laboratory, Department of Engineering Physics and Math., Helsinki University of Technology, PO Box 2200, FIN-02150 HUT, Espoo, Finland

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(c) ASI Students	
Jean-Claude Debus	Institut Supérieur d'Electronique du Nord, 41 Boulevard Vauban, 59046 Lille, France
Sergey Nikitenko	CEA / Vallée du Rhône (Marcoule), DRDD / SEMP / SEC Bat 399 B.P. 171, 30207 Bagnols sur Ceze, France
Vladimir Abramov	Max-Planck-Institut für Metallforschung, Seestr. 75, D-70174 Stuttgart, Germany
Sascha Hilgenfeldt	FB Physik, Universität Marburg, Renthof 6, 35032 Marburg, Germany
Dietlef Lohse	FB Physik, Universität Marburg, Renthof 6, 35032 Marburg, Germany
Robert Mettin	Universität Göttingen, Buergerstr. 42-44, D-37073 Göttingen, Germany
Claus-Dieter Ohl	Universität Göttingen, Buergerstr. 42-44, D-37073 Göttingen, Germany
Dietmar Peters	University of Rostock, Department of Chemistry, Buchbinderstrasse 9, D-18051 Rostock, Germany
Ferren MacIntyre	Expert-Center for Taxonomic Identification, PB 94766, NL-1090GT Amsterdam, The Netherlands
Massimo Germano	Dipartimento di Energetica, Università degli Studi di Roma, Via Antonio Scarpa, 14/16-00161 Rome, Italy
Italo Mazzarino	Politechnico di Torino, Dip. Scienze dei Materiali e Ingegneria Chimica, c. Duca degli Abruzzi 24, 10129 Torino, Italy
Giuliano Muzio	Dipartimento di Energetica, Università degli Studi di Roma, Via Antonio Scarpa, 14/16-00161 Rome, Italy
Marco Yanni	Politechnico di Torino, Dip. Scienze dei Materiali e Ingegneria Chimica, c. Duca degli Abruzzi 24, 10129 Torino, Italy
Yuri Koltypin	Bar-Ilan University, Department of Chemistry, Ramat-Gan 52900, Israel

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<b>(c) ASI Students</b>	
Shigeo Hayashi	Dept. of Applied Physics and Chemistry, University of Electro-Communications, 1-5-1 Chofugaoka, Chofu, Tokyo 182, Japan
Norio Miyoshi	Department of Pathology, Fukui Medical School, Matsuoka, Yoshida-gun, Fukui 910-11, Japan
Zsolt Lazar	Physics Institute- Theoretical Physics Section, University of Bergen, Allegaten 55, N-5007 Bergen, Norway
Antonio Lopes	ITQB - Lab. Sist. Micro-Heterogeneous, Ap 127, P-2780 Oeiras, Portugal
Maria Jose Moreno	Laboratoria de Quimica Farmaceutica, Faculdade de Farmacia, Universidade de Coimbra, 3000 Coimbra, Portugal
Iskander Akhatov	Russian Academy of Sciences, National Academy of Sciences of Bashkortostan, 6, K. Marx St., Ufa, 450000 Bashkortostan, Russia
Yuri Didenko	Pacific Oceanological Institute, Russian Academy of Sciences, 43, Baltiyskaya Street, Vladivostok, Russia
Robert Nigmatulin	Russian Academy of Sciences, National Academy of Sciences of Bashkortostan, 6, K. Marx St., Ufa, 450000 Bashkortostan, Russia
Alexander Voskoboynikov	Research Institute of Chemistry and Technology of Organoelement Compounds, 38 Shosse Entuziastov, Moscow 111123, Russia
Anton Gaplovsky	Institute of Chemistry, Faculty of Natural Sciences, Comenius University, SK-842 15 Bratislava, Slovakia

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NAME	FULL OFFICIAL ADDRESS /Institution, Street, Town, Country
<b>(c) ASI Students</b>	
Nicolas Garcia	Consejo Superior de Investigaciones Cientificas, Instituto de Acustica, Calle Serrano, 144, 28006 Madrid, Spain
Meral Eral	Ege University, Institute of Nuclear Sciences, 35100 Bornova, Izmir, Turkey
Seref Kalem	TUBITAK - Marmara Research Center, Institute of Electronics, PO Box 21, 41470 Gebze / Kocaeli, Turkey
M. Serhat Ozyar	Middle East Technical University, Dept. of Electrical and Electronics Engineering, Odut, Ankara 06531, Turkey
John Blake	University of Birmingham, School of Mathematics and Statistics, Edgbaston, Birmingham B15 2TT, United Kingdom
Thomas Chou	Dept. of Applied Math and Theoretical Physics, Cambridge University, Silver Street, Cambridge CB3 9EW, United Kingdom
Jifeng Ding	Nene College of Higher Education, Moulton Park, Northampton NN2 7AL, United Kingdom
Mark Hodnett	National Physical Laboratory - Building 56, Queens Road, Teddington, Middlesex TW11OLW, United Kingdom
Giles Keen	University of Birmingham, School of Mathematics and Statistics, Edgbaston, Birmingham B15 2TT, United Kingdom

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NAME	FULL OFFICIAL ADDRESS (Institution, Street, Town, Country)
<b>(c) ASI Students</b>	
Gerald Diebold (O&R)	Brown University, Department of Chemistry, 324 Brook St., Providence, Rhode Island, 02912, USA
Cliff Frenslay (O&R)	Applied Physics Laboratory, University of Washington, 1013 NE 40th St., Seattle, Washington, 98105, USA
Albert Frost (O&R)	Dept. of Electrical and Computer Engineering, University of New Hampshire, 33 College Rd., Kingsbury Hall 247, Durham New Hampshire, 03824, USA
Robert Godwin (O&R)	Applied Theoretical and Computational Physics Division, Group XNH, Mail Stop F664, Los Alamos National Laboratory, Los Alamos, New Mexico, 87545, USA
Ram B. Gupia	Chemical Engineering, Auburn University, Auburn, Alabama, 36849, USA
David Hunicke	Advanced Sonic Processing Systems, 263 Bacon Pond Road, Woodbury, Connecticut, 06798, USA
Lou Kondic (O&R)	New York University, Courant Institute of Mathematical Sciences, 251 Mercer Street, New York, New York, 10012, USA
Sameer Madanshetty(O&R)	Dept. of Mechanical Engineering, Kansas State University, 339 Durand Hall, Manhattan, Kansas, 66506, USA
Philip Marston(O&R)	Washington State University, Department of Physics, Pullman, Washington, 99164, USA
Thomas Matula (C&R)	Applied Physics Laboratory, University of Washington, 1013 NE 40th St., Seattle, Washington, 98105, USA
Vladimir Misik	National Cancer Institute, National Institutes of Health, Building 10, Room B3-B69, Bethesda, Maryland, 20892, USA
William Moss (C&R)	Earth Science Department, Lawrence Livermore National Laboratory, L-200, Livermore, California, 94550, USA
Peter Riesz	National Cancer Institute, National Institutes of Health, Building 10, Room B3-B69, Bethesda, Maryland, 20892, USA
Linda Weavers (C&R)	California Institute of Technology, MC 138-78, Pasadena, California, 91125, USA
Paul Werner	3M Company, Metal Matrix Composites, Bldg. 60-1N-01, St. Paul, Minnesota, 55144, USA

SONOLUMINESCENCE AND SONOCHEMISTRY

18- 28 August 1997, Leavenworth, Washington, USA

Director: Lawrence A. Crum  
Applied Physics Laboratory  
University of Washington  
1013 NE 40th Street  
Seattle, WA 98105 USA

The general topics of Sonoluminescence and Sonochemistry involve the phenomenon of acoustic cavitation, in which a preexisting gas bubble is made to grow explosively and then collapse implosively by the action of the acoustic field. This growth and collapse sequence can lead to enormous energy concentrations, as much as twelve orders of magnitude. During the final stages of implosion, the gas contained within the imploding bubble can achieve pressures of kilobars and temperatures of kilokelvins. These temperatures can result in light emission--thus sonoluminescence (SL), and the creation of chemical radical species--thus sonochemistry (SC).

In general, physicists are interested in SL and chemists are interested in SC, and unfortunately, these two groups have not collaborated on projects that would permit a more general attack on these problems. Recently, it has been discovered that a single stable cavitation bubble can produce sonoluminescence each and every cycle, a phenomenon called single bubble sonoluminescence (SBSL). Because the temperatures and pressures involved with this intriguing system are estimated to be even hundreds of kilokelvins, an exciting new area of SL research has been developed. At our ASI meeting, it was also announced that sonochemistry has been observed for this single bubble, and thus a new area of sonochemistry research, single bubble sonochemistry (SBSC) is possible. There are enormous advantages of studying a single bubble for both SL and SC over the previous regimes of many bubbles produced by acoustic transducers.

At the ASI, large amounts of time were devoted to the presentation of experimental data on the phenomenon of SBSL. These data now add more support to the view that the temperatures within the sonoluminescing bubble are so hot that the oxygen and nitrogen molecules that are present in air are broken down into reactive species that form soluble compounds of nitrogen and oxygen. These new compounds are then removed from the oscillating bubble leaving only the noble gases remaining, such as argon. This "chemical reactor" model for SBSL gained many adherents.

The presentation of data that demonstrate that a sonoluminescing bubble can produce observable sonochemistry was also an important and interesting aspect of the ASI. Since sonochemistry has been difficult to study in the past because of the many bubbles that are typically formed within a cavitation field, the development of a system for studying SBSC is considered an important contribution to the field.

An additional topic of much discussion was the physical mechanism(s) that lead to the light emission from SBSL. A strongly held theory is that imploding shock waves are developed within the gas during the later stages of bubble collapse. A second view is that asymmetrical collapses of the bubble can lead to liquid jets that penetrate the opposite bubble wall and generate light emission by fractoluminescence. These and many other theories were hotly debated and further calls were made to the experimentalists for additional data.

In general, the large number of international experts that were in attendance and the excellence of the presentations lead to a highly regarded and extremely successful conference.

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Main lectures given

Overview of Acoustic Cavitation

Dr. R. Apfel, Yale University, New Haven, Connecticut, USA

Single Bubble Sonoluminescence

Dr. B. Barber, Technical Staff, Lucent Technologies, Murray Hill, New Jersey, USA

Acoustic Cavitation and Single Bubble Sonoluminescence

Medical and Other Applications of Power Ultrasonics

Dr. L.A. Crum, Applied Physics Laboratory, University of Washington, Seattle, Washington,  
USA

High-Power Ultrasonic Transducers

Dr. J. Gallego-Juarez, Instituto de Acustica del CSIC, Madrid, Spain

Acoustic Cavitation and Multibubble Sonoluminescence

Nonlinear Bubble Dynamics

Dr. W. Lauterborn, Drittes Physikalisches Institut, Universität Göttingen, Göttingen, Germany

Spectral Analysis in Sonoluminescence

Single-Bubble Sonochemistry

Dr. T. Lepoint, Institut Meurice-CERIA, Brussels, Belgium

Surface Oscillations and Asymmetrical Bubble Collapse

Dr. M. Longuet-Higgins, Department of Theoretical and Applied Maths, Cambridge University,  
Cambridge, United Kingdom, and Institute for Nonlinear Science, University of  
California San Diego, La Jolla, California, USA

Industrial Applications of Sonochemistry and Sonochemical Environmental Remediation

Introduction to Organic Chemistry

Dr. T. J. Mason, School of Chemistry, Coventry University, Coventry, United Kingdom

Introduction to Macromolecular Chemistry

Sonochemistry of Polymers

Dr. G. Price, Department of Chemistry, University of Bath, Bath, United Kingdom

Old-fashioned Bubble Dynamics

The Collapse of Translating Bubbles

Dr. A. Prosperetti, Department of Mechanical Engineering, Johns Hopkins University, Baltimore,  
Maryland, USA

Introduction to Physical Chemistry

Homogeneous Non-aqueous Sonochemistry

Mass Transfer Promoted by Acoustic Cavitation

Dr. J. Reisse, Service de Chimie Organique, Université Libre de Bruxelles, Bruxelles, Belgium

Basic Acoustics, Propagation, Standing Waves, Terminology

Cavitation Sonophysics

Dr. R. A. Roy, Department of Aerospace and Mechanical Engineering, Boston University, Boston,  
Massachusetts, USA

Fundamentals of Organic and Inorganic Chemistry

Heterogeneous Sonochemistry and Sonochemistry of Protein Microspheres

Sono-catalysis

Multi-bubble Sonoluminescence

Dr. K. S. Suslick, School of Chemical Science, University of Illinois at Urbana-Champaign,  
Urbana, Illinois, USA

Organizing Committee

Dr. L.A. Crum (Director), Applied Physics Laboratory, University of Washington, USA

Dr. T.J. Mason, Coventry University, Coventry, United Kingdom

Dr. J.L. Reisse, Université Libre de Bruxelles, Bruxelles, Belgium

Dr. K.S. Suslick, School of Chemical Science, University of Illinois, USA

Publication

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